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REPORT No. 9/R/59

The Electrostatic Spark Sensitiveness of Initiators: Part 4: Initiation of Explosion by Spark Radiation

D. B. Scaife

Waltham Abbey
Essex.

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by

D.B. Scaife

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1. SUMMARY

The investigation is an attempt to determine the importance of the light absorbed by an explosive when ignition is produced by an electrostatic discharge. A major part of the work was concerned with the initiation of explosion in normal lead 2,4-dinitroresorcinate, R.D.1337, by flashes of ultraviolet light and it was found, for this material, that a certain peak intensity of light was a necessary requirement for ignition.

A chemical actinometer was used to measure the total energy of the light pulse and the results, together with the arbitrary intensity/time characteristic of the flash, enabled calculations of absolute light intensity to be made; arbitrary intensity/time traces were determined by the use of a photomultiplier tube working in conjunction with an oscilloscope.

For the ignition of R.D.1337 by an electrostatic spark it was estimated that if 2 - 3 per cent of the stored condenser energy appeared as u.v. light in the discharge, then the effect of the light alone might be responsible for the initiation of the explosion. Measurements of the light efficiency of condenser sparks led to the conclusion that the radiation effect was very important in the electrostatic spark ignition of R.D.1337.

The mechanism of the light initiation process in normal lead 2,4-D.N.R. is discussed briefly.

2. INTRODUCTION

In recent years, a comprehensive study of the ignition of primary explosives by electrostatic discharges has been carried out by workers at E.R.D.E. (1, 2, 3). Much of the information gained from this investigation was obtained by changing the discharge circuit parameters and observing the effects on the ignition probability. This technique enabled the limiting conditions for ignition to be established and the results made a valuable contribution to our understanding of the electrostatic hazards associated with initiatory materials. Apart from some ignition delay measurements with unidirectional gaseous discharges on lead azide, which suggested a thermal process (2) for this material, information relating to the mechanism of the initiation step has not been obtained. This aspect of the problem is the concern of the present study.

When a gaseous condenser spark takes place in air, energy is dissipated in several different forms. For instance, it appears as heat in the channel of hot gases and as radiation in the spark spectrum; energy is also associated with the shock wave produced by the discharge and with the electron beam flowing between the electrodes. It is quite probable, therefore, that the ignition of an explosive by a condenser spark, as described previously (2, 3), will be due to a combination of these effects although some will play a more important part than others. An obvious method for investigating initiation processes is to determine the effect on explosives of each of the above mentioned types of energy impulse, taken separately. It was considered that the bombardment of the explosive by electrons would contribute little to the total effect owing to the low energy of the electrons in this particular type of discharge. The shock wave effect was also considered to be of minor importance. Of the remaining contributions, the presence of hot gases in spark channel would be expected to be an important factor in the initiation process but unfortunately this effect is extremely difficult to isolate from the other spark phenomena.

/In .....

In the present work, attention has been focussed on the radiation emitted by a spark. This effect is likely to be important since it is well known that explosives can be ignited by high-intensity light flashes; moreover, radiation from a spark is easily isolated from the other phenomena, thus lessening some of the experimental difficulties.

3. MODERN STUDIES OF THE INITIATION OF EXPLOSIVES BY LIGHT

An excellent review of modern studies of the ignition of explosives by light has recently been made by Bowden and Yoffe (4), and it is only necessary here to give a brief outline of this work. Detailed investigations of the initiation by light have been carried out on a limited number of explosives only; these include silver azide (5, 6), silver nitride (7), nitrogen iodide (7, 8), and lead styphnate (9). Eggert (10, 11) has studied other primary explosives but in somewhat less detail.

The results indicate that, for most explosives, the initiation mechanism is photothermal in character; that is, the light absorbed by the crystals is very rapdily degraded into heat producing a sufficient increase in the temperature of the surface layers for the explosion to develop by a normal thermal process. For inorganic azides the situation is probably different. Evans (6) has suggested that the initiation process is truly photochemical, resulting in the production of neutral azide radicals. Subsequent growth of the reaction to explosion, however, is expected to proceed by a thermal mechanism, the heat controlling this process being supplied by the exothermic combination of azide radicals.

4. EXPERIMENTAL

4.1 Introduction

In this investigation a condenser spark taking place in air between steel electrodes was used as the source of radiation. The light was focussed by means of a quartz lens on to a known area of explosive sample. Under these conditions, only a small fraction of the light from the spark could be utilised and it was necessary to use extremely high energy discharges in order to obtain ignitions.

The first part of the work was concerned with the determination of a criterion for ignition and this was established, for normal lead 2,4-D.N.R., in terms of arbitrary values of light intensity. It was then necessary to put the results on a quantitative basis in order that the importance of the radiation effect in electrostatic spark ignitions of this material could be assessed. This is described in the second half of the experimental investigation.

4.2 Apparatus

The apparatus (Figure 1) consisted of a 16 μF (10 kV. wkg.) capacitor, the terminals of which were connected via short lengths of thick brass rod to two steel balls (0.48 cm. diameter) serving as the electrodes. One condenser terminal was maintained at earth potential and a section of the brass lead in this side of the circuit was removed so that modifications could be made to the parameters (resistance and inductance) which controlled the discharge characteristics; normally, a straight piece of 10 s.w.g. copper wire occupied this section of the circuit. The other condenser terminal was connected to a

/variable .....

variable high voltage supply which operated in the range 0 to 12 kV. The spark gap was adjusted so that the potential gradient at 10 kV was just less than the breakdown gradient. A small spark from an ignition coil, taking place between a third electrode and the main earth electrode, was used to trigger off the main discharge.

Light from the spark was collected by a biconvex quartz lens (f.2) placed below the spark gap at a distance equal to its focal length. Parallel light from this lens was focussed by means of a second similar lens on to a sheet of steel (10 cm. x 10 cm. x 1.5 mm.) containing a 0.3 cm. diameter hole at its centre. This metal sheet formed the top side of a box arrangement in which either a steel roller, a photomultiplier tube or an actinometer cell could be clamped immediately beneath the hole (cf Figure 1). With the metal roller in position, the cavity so formed was filled with particles of the explosive sample under test. The aluminium screen attenuated the spark shock wave and also protected the photomultiplier tube circuit from the troublesome electrical interference associated with the discharge.

The light intensity/time characteristics of sparks were determined using a Mazda 27M3 photomultiplier tube connected as a five-stage multiplier and working from a stabilised power supply of 600 V. When housed in the apparatus, the viewing aperture in the phototube case was made to coincide with the hole in the metal sheet. The phototube signal was fed into a Cossor 1035 Oscilloscope which triggered at the commencement of the spark and the intensity/time trace was photographed in the usual way. In order to obtain a signal of appropriate magnitude, it was necessary to restrict the amount of light entering the phototube by placing a diaphragm over the quartz lens system. This diaphragm was removed during ignition and actinometer experiments.

4.3 Preliminary Ignition Experiments

In the initial experiments, a straight piece of 10 s.w.g. copper wire completed the open section of the discharge circuit and a sample of explosive occupied the position indicated in Figure 1. The voltage on the condenser was increased in increments of 100 until an ignition occurred, a fresh sample of explosive being used for each irradiation. In this way it was possible to determine the critical voltage required for ignition; this was taken as the highest voltage at which no ignition in five trials was observed. For most materials it was found that 100 per cent ignitions were obtained when the flash voltage exceeded the critical ignition voltage by 100. Table 1 gives the critical voltages for a range of primary explosives.

/TABLE 1 .....

TABLE 1

Material	Critical Ignition Voltage, kV.
Lead styphnate, R.D.1303	7.2
Lead styphnate, R.D.1303M	7.8
Basic lead styphnate, BLS 122	4.5
Barium styphnate, R.D.1340	No ignition at 10.5
Lead 2,4-D.N.R., R.D.1337	5.2
Service lead azide, Cy 3628	No ignition at 10.5
Silver azide, R.D.1336	No ignition at 10.5
Mercury fulminate	9.8
Tetrazene	7.0

It will be noticed that normal lead 2,4-D.N.R. (R.D.1337) and basic lead styphnate (BLS 122) are the most sensitive of this group of explosives towards pulses of light energy. Lead styphnates R.D.1303 and R.D.1303M appear appreciably less sensitive, with critical ignition voltages in the same region as that of tetrazene. Samples of Service lead azide (Cy 3628) and silver azide (R.D.1336) could not be ignited even at the maximum permissible condenser voltage, although a darkening of the surface crystals, indicating some decomposition, was evident at flash voltages greater than about 8 kV. in both cases. An interesting point in connection with the sensitiveness order is that the electrostatic sensitiveness towards true gaseous sparks (2) of lead styphnate and dinitroresorcinates is far greater than for silver and lead azides.

It was anticipated that by increasing the discharge circuit parameters and by using filters to select certain wavebands of light, higher voltages would be required to produce ignitions. Since the maximum voltage to which the condenser could be charged was about 10 kV. it was likely that a detailed investigation would be possible for the more sensitive materials only. This was found to be the case and the main investigation centred on normal lead 2,4-D.N.R. since this material, in addition to being sensitive, was also well defined and available in the pure state, as R.D.1337.

4.4 Detailed Investigation of Lead 2,4-D.N.R., R.D.1337.

4.4.1 Effect of the Wavelength of the Radiation

In an attempt to determine which wavelength region of the spark spectrum was important in producing ignition in R.D.1337, certain filters were placed in the light beam and the effect on the critical ignition voltage was observed. Unfortunately, filters for the selection of narrow wavebands in the visible and near ultraviolet were not readily available. Some of the filters used, e.g. certain organic solvents, transmitted the whole of the visible spectrum

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and had a sharp cut-off at some point in the ultraviolet. Only two filters (Chance OX7 and OX1) were of the type which transmitted a fairly narrow band of wavelengths.

With no filter in position, the quartz lenses of the optical system absorbed all wavelengths less than about 200 mμ and the ignition voltage was 5.2 kV. The wavelength cut-off was increased, first to 270 mμ using a filter of carbon tetrachloride (1 cm.), and then to 320 mμ with an acetone filter (1 cm.); the corresponding critical ignition voltages were 7.3 kV and 9.2 kV, respectively.

The results of three further experiments are of interest:

(i) Using a Chance ON20 filter (transmission range 300 - 700 mμ) no ignitions were obtained.

(ii) When the light was restricted to a waveband of 240 - 420 mμ by means of a Chance OX7 filter, the critical ignition voltage was 7.2 kV.

(iii) Ignitions could not be obtained when a Chance OX1 filter was used. This filter was similar to the OX7 but had a narrower pass-band (300 - 400 mμ).

The results clearly indicate that the light from the spark in the wavelength range 200 - 300 mμ is important in producing ignitions in R.D.1337. It is not possible to draw any further conclusions since two important factors, i.e., the spectral distribution of the light energy and the absorption spectrum of the explosive crystals, were not known. The absorption spectrum of normal lead 2,4-D.N.R. crystals in the visible and ultraviolet cannot easily be determined because of the difficulty of obtaining crystals of suitable dimensions. However, it is interesting to note that a solution of normal lead 2,4-D.N.R. in ammonium acetate has a fairly steep absorption edge in the wavelength range 450 - 500 mμ and absorbs strongly throughout the near ultraviolet; in the region 550 - 1000 mμ the absorption is negligible.

It was planned at a later stage in the investigation to measure, by means of an actinometer, the total energy of light pulses. Since accurate determinations of this kind would require the use of monochromatic light, it was desirable to select a suitable filter for use in future experiments. The Chance OX7 filter was chosen. Whilst the light selected by this filter was by no means monochromatic, the pass-band was in the appropriate region of the spectrum for the present purpose and, further, sufficient light to produce ignitions in R.D.1337 was transmitted. In addition to the main pass-band (240 - 420 mμ with a peak transmittance at about 340 mμ) the OX7 filter also passed a small amount of light in the near infrared. This was considered unimportant since ignitions could not be obtained when a Chance OX2 filter, transmitting only near infrared radiation, was placed in the light beam. Further, both the photomultiplier and actinometer were relatively insensitive in this region of the spectrum.

4.4.2 Effect of Changes in the Discharge Circuit Parameters

Before carrying out this part of this investigation it was found that ignitions could be obtained at somewhat lower voltages if the explosive sample was moved from the focus of the light beam to a position about 1 cm. nearer the lens system. This phenomenon cannot easily be explained. However, all subsequent determinations of the critical voltage for ignition were carried out with the explosive sample in this new position, since it was then possible to vary the circuit parameters to a greater extent whilst still obtaining ignitions.

/Variations .....

Variations were first made in the inductance of the discharge circuit. This was done by replacing the straight length of 10 s.w.g. copper wire, which formed the removable section of the circuit, with a coil consisting of 4 turns (2.5 cm. diameter) of the same wire. The critical ignition voltage was then determined as described in Section 4.3. This experiment was repeated after increasing the inductance still further by first, replacing the coil of 4 turns with one of 12 turns and then substituting a coil of 18 turns. The effect of increasing the circuit resistance was found by replacing, successively, the coil of 18 turns with straight lengths of 14 s.w.g., 16 s.w.g. and 18 s.w.g. Nichrome wire and, for each condition, determining the critical ignition voltage as before.

The results can be found in Table 2 (p. 13) which will be considered in more detail later. It will be noted that increases in both inductance and resistance produce increases in the critical ignition voltage of R.D.1337.

4.4.3 Intensity/time Characteristics of Critical Pulses

For each set of circuit conditions considered in Section 4.4.2 an intensity/time trace was determined (cf Section 4.2) at the corresponding critical ignition voltage. In these experiments the Chance OX7 filter was retained. The critical light pulses so obtained are reproduced in Figure 2 which shows that an increase of inductance lengthens the duration of the light pulse whereas the addition of resistance has the opposite effect. Spark durations and the times to peak intensity are included in Table 2. Arbitrary values of peak intensity ($I_p^{arb.}$) and total pulse energy (area under the intensity/time curve) are indicated in Figure 2. The slight fluctuations in intensity, shown on these traces, are probably due to the oscillatory nature of the current/time characteristics of the sparks.

An important point of interest is that the arbitrary peak intensities of these critical pulses are approximately the same whereas the total energy values vary considerably. This suggests that a necessary requirement for the ignition of normal lead 2,4-D.N.R. is that the intensity of the light should attain a certain peak value.

Although the peak intensities of the critical pulses are reasonably constant, the differences are just about significant as shown by the following argument. The maximum difference between any two peak intensities of Figure 2 is about 0.9 division, i.e., the difference in the values given by Expts. 1 and 4. Since the variation of peak intensity with flash voltage was about 0.2 division per 100 V., then the voltage indicated for Expt. 1 would need to be increased by approximately 500 in order to raise the peak intensity to that of Expt. 4. Such a voltage increase is significantly greater than the errors involved in the determination of the critical ignition voltage (± 100 V. at about 6 kV.).

However, the small differences in the peak intensity values can be explained satisfactorily in terms of the photomultiplier response and the energy distribution in the spark spectrum. The response of the phototube was not linear over the wavelength range selected by the Chance OX7 filter. If the spectral energy distribution of each type of spark considered is not the same then light intensity values recorded by the photomultiplier tube (i.e. integrated over the whole waveband) will not be strictly comparable. The discrepancies should be resolved when the results are put on to a quantitative basis, i.e. by measuring the absolute total energy of the pulses by an independent method and calculating absolute values of the light intensity. An attempt to do this is described in the next section.

/4.5 .....

4.5 Measurement of the Total Energy of Light Pulses

4.5.1 Introduction

It is possible to determine the energy of light pulses by the use of a chemical actinometer. This technique involves measuring the extent of decomposition of some light-sensitive solution and, from a knowledge of the quantum efficiency of the chemical reaction, calculating the number of light quanta which have passed into the actinometer cell. It is evident that, if a fairly wide range of wavelengths is used to irradiate the solution, as in the present work, then an accurate determination of the total number of quanta is only possible when the quantum efficiency is constant over the spectral region considered. Calculations of the total light energy from the total number of quanta is a simple matter for monochromatic light. However, approximations have to be made when a range of wavelengths is considered unless the spectral distribution of the light is known.

4.5.2 The Use of Potassium Ferrioxalate in Actinometry

When a solution of potassium ferrioxalate is irradiated with visible or ultraviolet light it decomposes to give ferrous oxalate, which does not precipitate if the reaction is carried out in an acidic medium. The concentration of ferrous ions can be estimated by adding a solution of 1,10-phenanthroline and measuring the optical density of the coloured complex produced, the ferrous ion concentration being read off directly from a calibration curve.

An actinometer technique employing potassium ferrioxalate as the photolyte has been developed by Parker and his colleagues (12, 13). The sensitivity of this actinometer was found to be about 100 times greater than the uranyl oxalate actinometer. This is mainly attributed to the fact that trace quantities of the decomposition product (Fe^{2+}) can be estimated accurately by the colorimetric method outlined above. During the course of his investigation, Parker determined the quantum efficiency of the potassium ferrioxalate reaction over a wide range of wavelengths.

The potassium ferrioxalate actinometer was ideal for the present work since it fulfilled three important requirements:

(i) The sensitivity was extremely high so that it could be used to measure the energy of light pulses of short duration.

(ii) The quantum efficiency of the reaction was constant over the wavelength range transmitted by the Chance OX7 filter, i.e. 240 - 420 mμ. This facilitated the calculation of the total number quanta in a light pulse.

(iii) The photolyte was insensitive in the infrared region where the OX7 filter transmitted a secondary waveband.

The simple actinometer cell designed by Parker was not suitable for measuring the very small light energies of the flashes used in the ignition experiments. A special actinometer cell was constructed to fit the present requirements.

4.5.3 Design of Actinometer Cell

The actinometer cell was designed in such a way that the maximum concentration of ferrous ions could be obtained for a given amount of incident light, i.e., the volume of irradiated solution was kept to a minimum. The position in

/which .....

which the cell was to be used in the measurement of light pulse energies influenced the shape of the photolyte compartment. The viewing window of the cell was to be placed directly beneath the small hole in the top side of the holder shown in Figure 1 to ensure that exactly the same amount of light, for a given flash, entered the actinometer cell as fell on the explosive sample during the ignition experiments. With the cell in such a position relative to the light beam, i.e. approximately at the focus of the light, it was possible to have a cone-shaped compartment for the photolyte. The depth of this compartment was adjusted so that the incident light, for the particular concentration of photolyte used, was completely absorbed. Two other compartments, one containing the complexing solution, the other a mixing compartment, were housed in the actinometer cell (Figure 3) so that the coloured complex could be produced in situ. In this way, the maximum concentration of coloured complex was obtained.

The two glass balls in the top compartment (Figure 3) allowed the photolyte to be stirred between flashes (it will be seen later that more than one flash was required to produce a measurable quantity of ferrous ions).

4.5.4 Energy Measurements

The following procedure was adopted. The actinometer cell, containing the photolyte (0.06 M potassium ferrioxalate) and the complexing solution (1 per cent 1,10-phenanthroline in a sodium acetate/0.1 N sulphuric acid buffer solution) in their respective compartments, was clamped in the correct position inside the cell holder. After irradiation, the photolyte was mixed with the complexing solution and transferred directly to a 1 cm. quartz absorption cell. A Unicam absorption spectrophotometer was used to measure the optical density of the solution at 510 mμ, the wavelength at which the absorption of the coloured complex was a maximum; the "blank" solution used for comparison was made by mixing a sample of the original photolyte (i.e. not irradiated) with the same proportion of complexing solution. A calibration curve, showing the optical density of accurately made-up solutions of ferrous sulphate and 1,10-phenanthroline as a function of ferrous ion concentration, was used to read off the concentration of ferrous ions in the coloured solution. Since the volume of both the photolyte and complexing solution compartments was known, the concentration of ferrous ions in the irradiated photolyte, before mixing, could be calculated.

The total number of quanta entering the actinometer is given by

$$n_T = \frac{v\, C_1\, N}{1000\, Q} \qquad \ldots\ldots \quad 1$$

where v = volume of photolyte compartment (ml.),
C_1 = concentration of Fe^{2+} produced by the light flash (mole. litre^{-1}),
N = Avagadro's number (mole^{-1}),
Q = quantum efficiency of the light sensitive reaction.

Q was taken as 1.20, the value determined by Parker (13) over the wavelength range in question. n_T is the total number of quanta incident on an area πr^2 of the actinometer window where r (cm.) is the radius of the hole in the steel plate (Figure 1) through which the light passes. (Incidentally, πr^2 is also the area of the explosive sample irradiated during the ignition experiments.)

It follows that the total number of quanta per square centimetre falling on the actinometer is:

$$n_T^* = \frac{n_T}{\pi r^2} \qquad \ldots\ldots \quad 2$$

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In order to calculate the total energy/cm^2(E, ergs/cm^2) it is necessary to assume that the light is monochromatic. Since the waveband transmitted by the Chance OX7 filter was centred on 340 mμ, this wavelength (λ) was used to calculate the energy per quantum (ϵ_λ) from the relation $\epsilon_\lambda = hc/\lambda$, where h is Plank's constant and c the velocity of light.

This gives $\epsilon_\lambda = 5.84 \times 10^{-12}$ erg.

Hence $E = n_\tau^* \cdot \epsilon_\lambda = 5.84 \times 10^{-12} n_\tau^*$ 3

During preliminary experiments it was found that the quantity of light from a typical spark was insufficient to produce a concentration of ferrous ions which could be determined accurately. For a 7 kV. spark, (circuit conditions as for Expt. 1, Table 2) about eight flashes were needed to produce a satisfactory level of decomposition. Experiments in which the concentration of ferrous ions was measured as a function of the number of flashes showed that the relation $C_n = C_1 n$ held over the range n = 4 to n = 14; C_n is the concentration of ferrous ions produced by n flashes and C_1, the slope of the curve, is the energy per flash. Thus it was permissible to identify C_n/n with C_1.

The method was sensitive enough to detect differences in the light output of sparks differing only by about 3 to 5 per cent in flash voltage. This is comparable to the accuracy with which critical ignition voltages could be determined.

The actinometer experiments were concerned mainly with the measurement of the total light energy of the critical pulses shown in Figure 2. For each set of circuit conditions the amount of photolyte decomposition per flash was determined at the corresponding critical ignition voltage. Values of n_τ^* and E were calculated from equations 1, 2 and 3 and the results are recorded in Table 2 (p.11).

4.5.5 Calculation of Absolute Light Intensities

For each critical pulse both the total energy and the arbitrary intensity/time traces are known. It is possible, therefore, to fix the intensity scale in terms of absolute units and hence obtain values of absolute peak intensity, $I_p^{abs.}$.

If $I_t^{abs.}$ is the absolute intensity of light, measured in quanta. $cm^{-2}s.^{-1}$, at some time t seconds during a spark pulse, then the total number of quanta/cm^2 (n_τ^*) for the pulse is given by

$$n_\tau^* = \int I_t^{abs} \, dt.$$

Suppose that S (division^2) is the area under the arbitrary intensity/time curve, x (s.division^{-1}) is the time scale factor and y (quanta.cm^{-2}.s.$^{-1}$division^{-1}) the intensity scale factor, then

$$n_\tau^* = \int I_t^{abs} \, dt = S.x.y.$$

S.x can be obtained directly from the intensity/time trace and hence y can be calculated if n_τ^* is known. I_p^{abs} is then given by the equation

$$I_p^{abs} = y. I_p^{arb}$$

where I_p^{arb} is the arbitrary peak intensity (divisions). Values of Sx, y, I_p^{arb} and I_p^{abs} are included in Table 2.

/It .....

It was hoped that the calculations of I_p^{abs} would confirm the indications of the earlier experiments that a certain peak intensity was an essential requirement for the ignition of normal lead 2,4-D.N.R. However, the values of I_p^{abs} show much greater variations than I_p^{arb} values (cf. Table 2). By comparing values of I_p^{abs} with the corresponding spark durations it is seen that the highest values of I_p^{abs} are associated with the sparks of shortest duration. This seems to suggest that there is some kind of saturation effect, connected with the photolytic reaction, which increases with the flash duration. Thus the calculated energies (and hence also the values of I_p^{abs}) of the longer duration sparks are probably appreciably less than true values. Although variations in absolute peak intensity are quite large, the variations in total pulse energy are much greater.

Previous work on the potassium ferrioxalate actinometer (12, 13) had dealt mainly with prolonged irradiation using light of low intensity and the saturation effect, described above, had not been observed.

5. DISCUSSION

5.1 Criterion for the Ignition of Lead 2,4-D.N.R., R.D.1337

Both the photomultiplier traces and absolute total energy determinations of critical light pulses showed that a criterion for the ignition of R.D.1337 based on the total energy of the light absorbed was not acceptable. The arbitrary intensity/time curves indicated, quite clearly, that the requirement for ignition was a certain peak intensity of light. Unfortunately, this condition was not substantiated by calculations of absolute peak intensity values but a likely explanation for the non-agreement was put forward.

From this evidence, it was concluded that the intensity of ultraviolet light falling on the explosive sample must attain a certain peak value before initiation is possible. Under these conditions, the first observable stages of the decomposition might be expected to be reached shortly after the attainment of the peak intensity. An attempt was made, therefore, using an ion probe technique, to measure the time interval between the commencement of the spark and first signs of ignition. However, this method gave time intervals, for several types of spark, which greatly exceeded the flash durations. Such a situation seems extremely unlikely. It is known that on the ignition of normal lead 2,4-D.N.R. there is a period of burning before detonation occurs. A likely explanation, therefore, of the "apparent" long delays is that the ion probe is only sensitive enough to detect the onset of detonation and not the initial combustion stage. It is of interest to note that Meerkämper (8), working on the light initiation of nitrogen iodide, found that the time to ignition did coincide with peak intensity of the light pulse.

5.2 Mechanism of the Light Initiation Process

When a material decomposes with the liberation of heat, a thermal explosion may result if the rate of heat production by chemical reaction exceeds the rate of heat loss to the surroundings. These conditions produce an acceleration in the rate of decomposition and may lead to an explosion. Most explosions probably develop by such a mechanism, irrespective of the initiation process, which may be due to heat, shock or light.

/TABLE 2 .....

TABLE 2

Characteristics of Critical Light Pulses

	Circuit Conditions	Critical Voltage, kV	Light Duration of Pulse, s	Time to Peak Intensity, s	I_p^{arb}, divisions	S.x, s.divisions	n_T^*, quanta.cm^{-2}	E, ergs.cm^{-2}	y, quanta.cm^{-2}.s^{-1}.division^{-1}	I_p^{abs}, quanta.cm^{-2}.s^{-1}
1	Straight 10 s.w.g. copper	5.3	140	~ 20	7.6	8.3×10^{-4}	1.10×10^{17}	6.4×10^{5}	1.32×10^{20}	10.0×10^{20}
2	4 turns 10 s.w.g. copper	5.8	180	~ 40	7.8	11.0×10^{-4}	1.32×10^{17}	7.7×10^{5}	1.21×10^{20}	9.4×10^{20}
3	12 turns 10 s.w.g. copper	7.4	390	~ 170	8.4	21.4×10^{-4}	2.40×10^{17}	14.0×10^{5}	1.23×10^{20}	10.3×10^{20}
4	18 turns 10 s.w.g. copper	8.7	390	~ 200	8.5	21.7×10^{17}	2.90×10^{17}	12.2×10^{5}	0.96×10^{20}	8.2×10^{20}
5	Straight 14 s.w.g. Nichrome	6.0	100	5 - 10	8.0	5.19×10^{-4}	0.93×10^{17}	5.5×10^{5}	1.80×10^{20}	14.4×10^{20}
6	Straight 16 s.w.g. Nichrome	7.1	90	5 - 10	7.9	4.00×10^{-4}	0.78×10^{17}	4.6×10^{5}	1.96×10^{20}	15.5×10^{20}
7	Straight 18 s.w.g. Nichrome	8.2	80	5 - 10	8.3	4.23×10^{-4}	0.91×10^{17}	5.3×10^{5}	2.14×10^{20}	17.8×10^{20}

In simple terms, the initiation process is concerned with raising the temperature of the explosive to a critical temperature at which the rate of heat production by chemical reaction becomes the major factor controlling the thermal development of the explosion. Considering the initiation of explosion by light pulses, two mechanisms are possible, i.e. photothermal or photochemical. In the photothermal process, the light absorbed is rapidly degraded into heat which raises the surface layers of the explosive to the critical temperature for ignition. If the treatment is simplified by ignoring heat losses during the initiation period, it follows that a fixed amount of light energy will be needed to produce the critical conditions. However, a more realistic approach would take into account the rate of heat loss to the surroundings; under these conditions a certain rate of heat input, i.e., a certain light intensity, will be required if the critical temperature is to be attained. A similar requirement will apply to initiation by a photochemical process in which the light absorbed produces direct chemical decomposition, the heat liberated raising the temperature of the surface layers.

Thus the criterion established for the ignition of normal lead 2,4-D.N.R. is consistent with both types of mechanism but, from the limited amount of information available, a differentiation could not be made.

5.3 The Importance of the Light Effect in the Ignition of Lead 2,4-D.N.R., R.D.1337, by Electrostatic Sparks

The results obtained in Section 4 have been used to assess the importance of the light effect in the electrostatic spark ignition of R.D.1337. In the electrostatic test, using an approaching electrode apparatus (2) and a 500 $\mu\mu$F capacitor, R.D.1337 has a metal-metal threshold ignition energy of approximately 500 ergs (14); the initial voltage across the spark gap for this particular condenser energy is about 450 V. An estimation of the area of explosive sample irradiated under these conditions can be made. It will be remembered that the approaching needle electrode is brought down towards a flat steel base electrode on which stands the loose layer of explosive sample; the discharge occurs when the potential gradient exceeds the breakdown gradient and actually takes place within the layer of explosive particles. For the particular discharge in question, the length of the spark will be about 0.15 mm. which is of the order of twice the diameter of the crystal aggregates of R.D.1337. Assuming a close packed arrangement of these particles on the steel roller, calculations of the area of explosive irradiated gives a value of 0.0005 cm^2; this must be regarded as very approximate but is probably of the right order of magnitude.

An arbitrary intensity/time trace for this 500 $\mu\mu$F spark has been determined by the photomultiplier technique described earlier; this is shown in Figure 4. We now apply the criterion that a peak intensity of 10^{10} ergs/cm^2.s. is required to produce an ignition. This value was calculated from the peak intensity given by Expt. 7, Table 2 (i.e., from energy measurements of the shortest duration spark for which the saturation effect will be small) and refers, strictly, to light of wavelength 340 mμ. It will be convenient, here, to make a generalisation and say that the figure of 10^{10} ergs/cm^2 is the intensity of ultraviolet light necessary for ignition.

Thus the arbitrary peak intensity of the light trace of Figure 4 was identified with 10^{10} ergs/cm^2 and the area underneath the curve was then found to be 35,000 ergs/cm^2, which is the total ultraviolet light energy per square centimetre of irradiated sample, required to produce an ignition by the light effect alone. The area of the sample irradiated in the electrostatic test has been estimated as 0.0005 cm^2 and hence the corresponding total energy will be 17 - 18 ergs or about 3 per cent of the stored condenser energy.

/The .....

The percentage of the condenser energy which appears as ultraviolet light in a discharge of the type used in the electrostatic spark test is not easily measured, since the quantity of light emitted is extremely small. However, actinometric experiments, carried out on sparks produced by the 16 μF capacitor used for the light ignition experiments, showed that 10 - 15 per cent of the stored energy appeared as ultraviolet light.

It must be concluded, therefore, even allowing for large errors in the foregoing calculations, that the light radiating from the spark channel may be an important factor in the electrostatic spark ignition of normal lead 2,4-D.N.R., R.D.1337.

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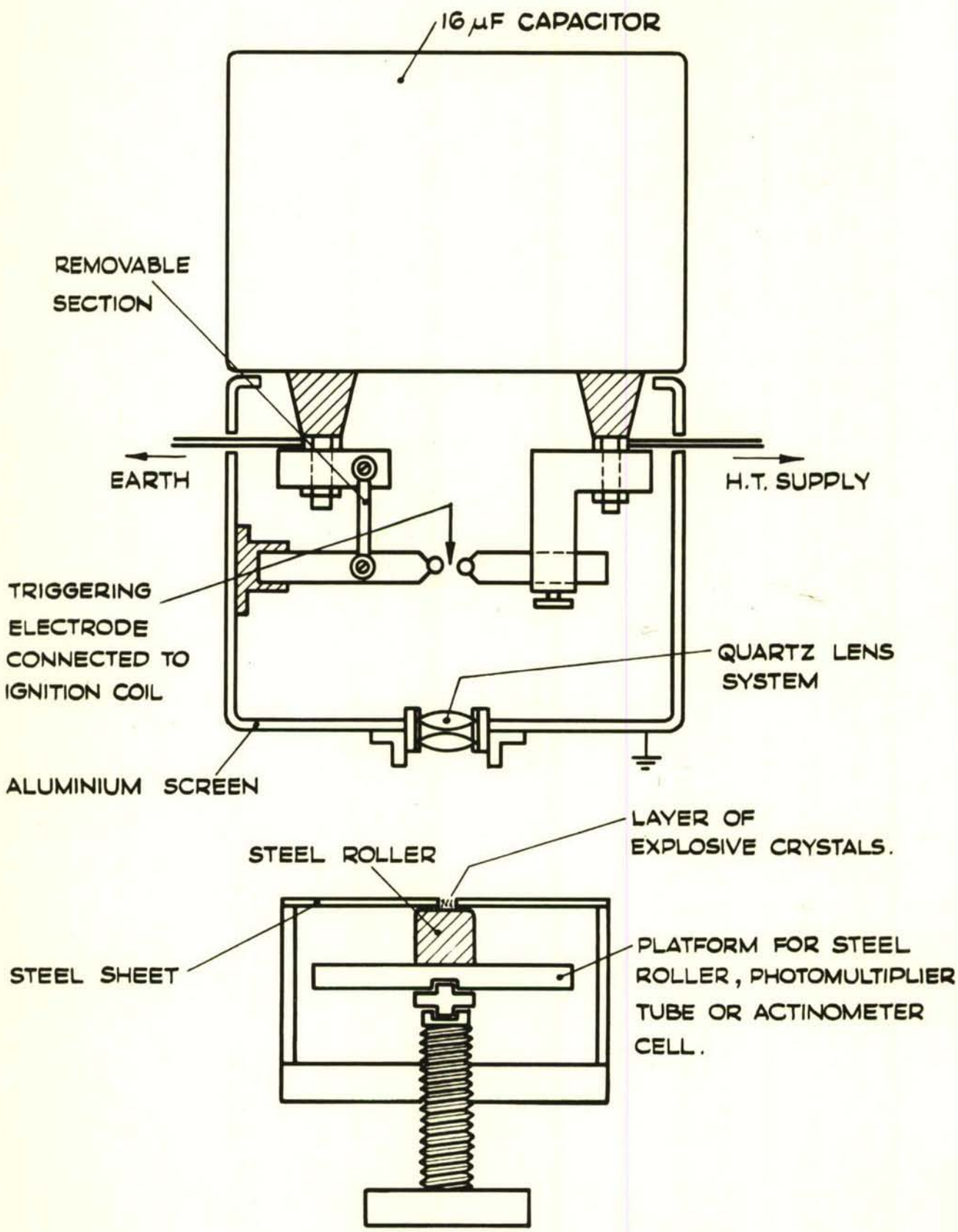
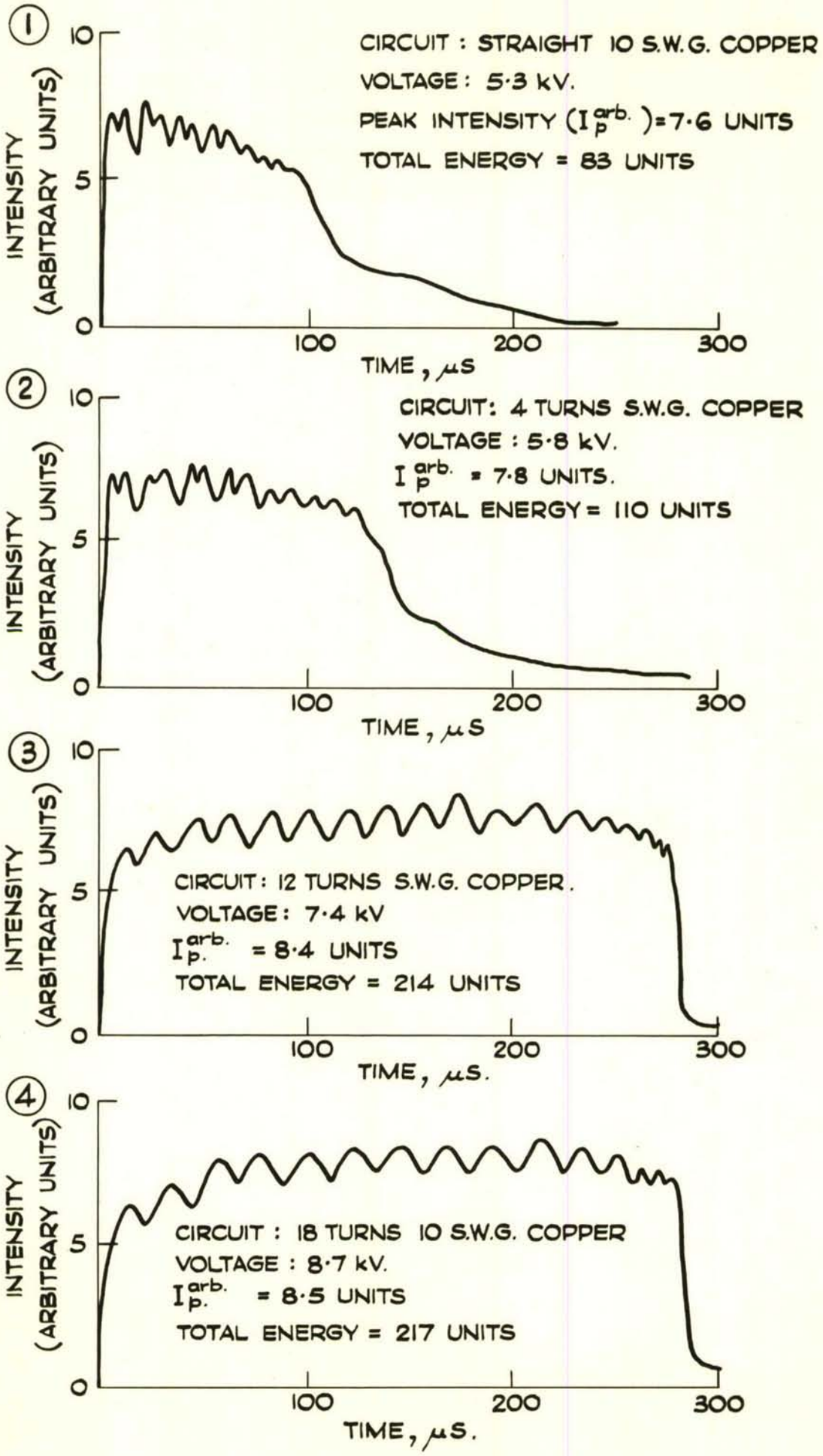
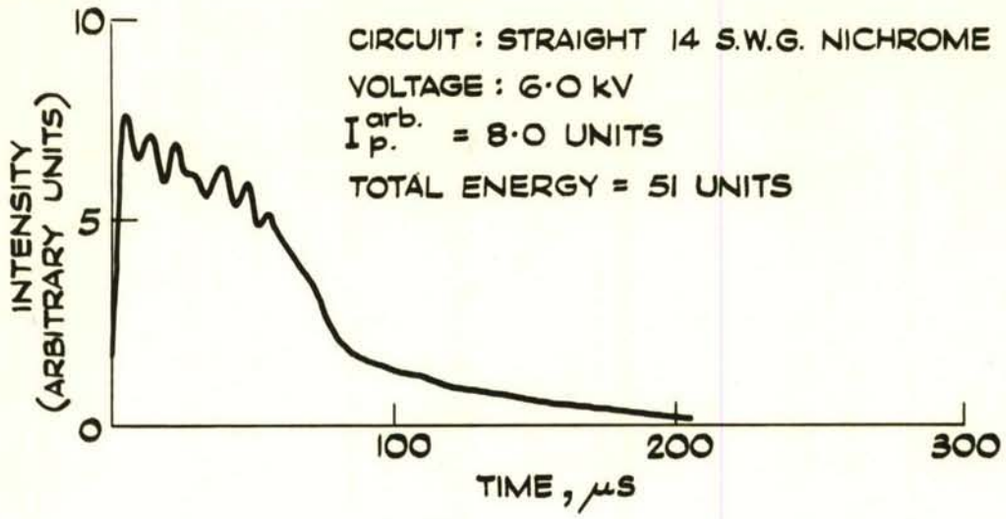
M. No. 429/59
S. No. 647/BIC

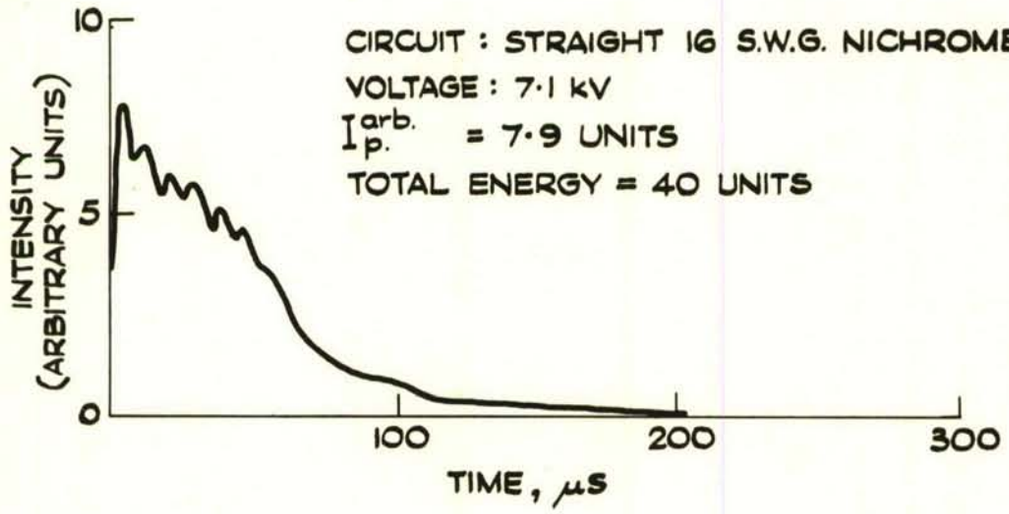


APPARATUS. FIG. 1.



PHOTOMULTIPLIER TRACES AT CRITICAL VOLTAGES FOR LEAD 2,4-D.N.R. FIG. 2.


CIRCUIT : STRAIGHT 14 S.W.G. NICHROME
VOLTAGE : 6·0 kV
$I_{p.}^{arb.}$ = 8·0 UNITS
TOTAL ENERGY = 51 UNITS
INTENSITY (ARBITRARY UNITS)
10
5
0
100
200
300
TIME, μs


CIRCUIT : STRAIGHT 16 S.W.G. NICHROME
VOLTAGE : 7·1 kV
$I_{p.}^{arb.}$ = 7·9 UNITS
TOTAL ENERGY = 40 UNITS
INTENSITY (ARBITRARY UNITS)
10
5
0
100
200
300
TIME, μs

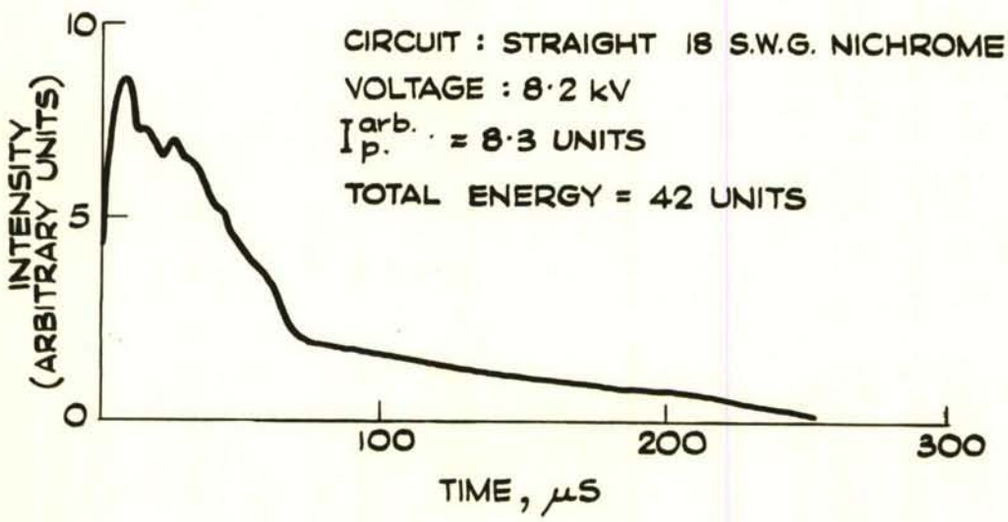
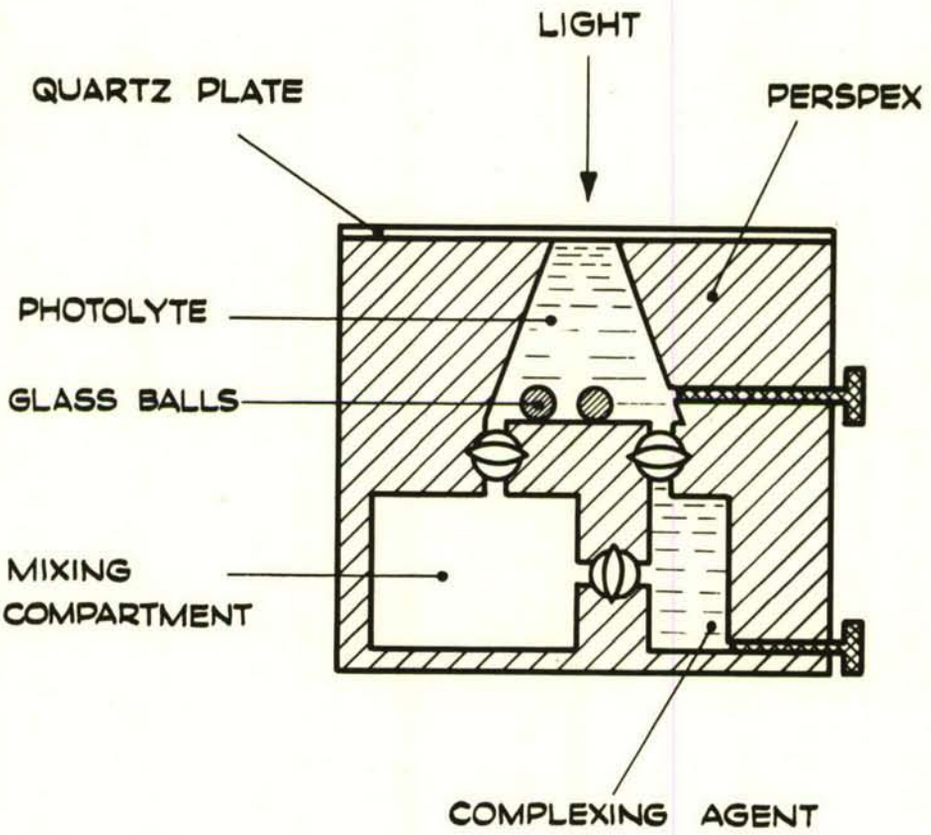
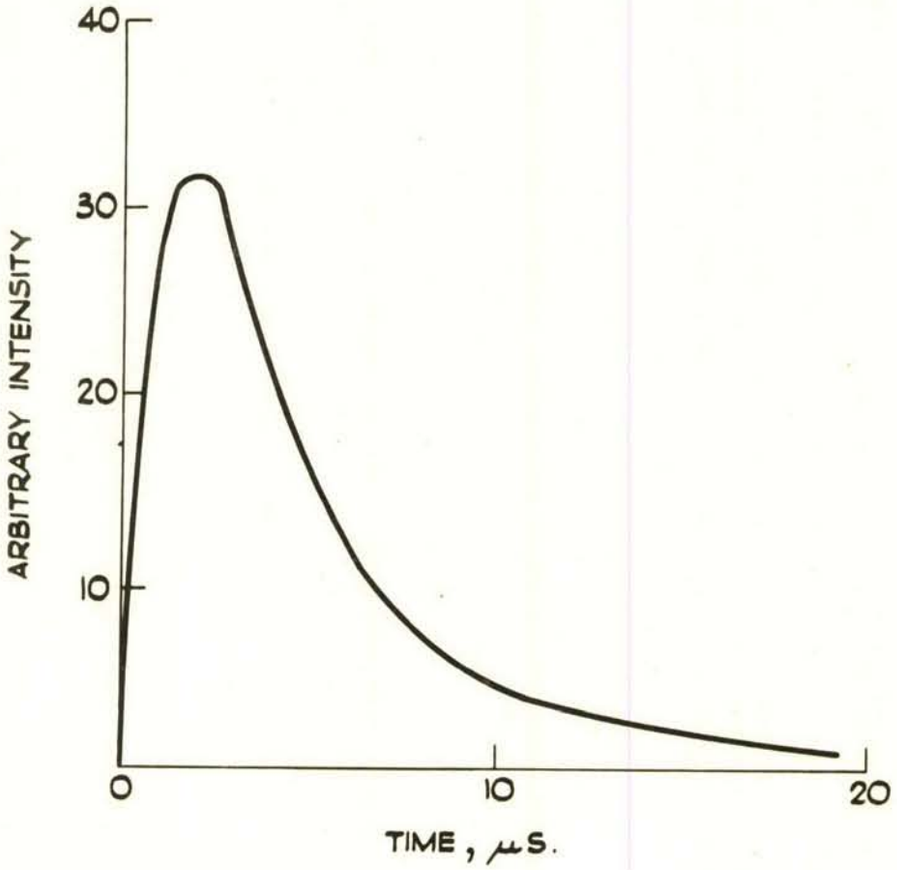

CIRCUIT : STRAIGHT 18 S.W.G. NICHROME
VOLTAGE : 8·2 kV
$I_{p.}^{arb.}$ = 8·3 UNITS
TOTAL ENERGY = 42 UNITS
INTENSITY (ARBITRARY UNITS)
10
5
0
100
200
300
TIME, μs

FIG. 2. (CONT.)



ACTINOMETER CELL. FIG. 3.



LIGHT PULSE OF A SPARK FROM A 500 μμF CAPACITOR CHARGED TO 450 V. FIG. 4.

E.R.D.E. Report No. 9/R/59

The Electrostatic Spark Sensitiveness of Initiators: Part 4: Initiation of Explosion by Spark Radiation

D.B. Scaife

October, 1959.

Primary explosives have been ignited by the radiation emitted by condenser discharges. A detailed investigation of normal lead 2,4-dinitroresorcinate, R.D.1337, showed that a certain peak intensity of light was a necessary requirement for the ignition of this material. An actinometer was used to determine the total energy of light pulses and the results were used, in conjunction with arbitrary intensity/time traces, to calculate absolute light intensities.

The information obtained was used to assess the importance of the light emitted by a condenser spark in the electrostatic spark ignition of normal lead 2,4-D.N.R., R.D.1337.

13 pp., 4 fig., 2 tables.

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